The Determination of the Aerosol Spatial Structure in the Lower Part of the Marine Atmospheric Boundary Layer from Horizontal Lidar Data

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LONG-TERM GOALS

The long-term goal is to establish reliable relationships between the environmental factors (such as wind, waves, air humidity, etc.) and the propagation of electromagnetic signals in the lower part of the marine atmospheric boundary layer (LP MABL).

OBJECTIVES

The present work is concerned with deriving microphysical characteristics of the maritime aerosol from the backscattered lidar signal. The goal of this year was to carry out massive tests of the inversion method of mean ordinates by the SEAS database, to apply the direct SEAS observations over the aerosol particle size distribution (APSD) as a constraint in the inverse problem, and to retrieve profiles of aerosol microphysical characteristics over the sea.

APPROACH

The inversion of lidar data into the aerosol particle size distribution (APSD) presents a complex and incorrect problem. The complexity is associated with the scarcity of optical data and, at times, with their insufficient accuracy. Usually one, two, at most three channels are used for horizontal lidar sounding. This is hardly enough for performing the inversion by the common methods.

At the earlier stage of this work, we have developed a method (method of mean ordinates) specifically intended for the inversion of scarce optical data into APSD [1, 2]. It is based on a quasi-stochastic approach. The method differs from other inversion methods of this kind in that the most probable solution to the inverse problem is defined as the closest aerosol model to the mean over all acceptable solutions. This prevents possible considerable inversion errors inherent in other methods.

The method makes it possible to retrieve, under certain conditions, APSD from lidar data at two and even one wavelength with retrieval accuracy comparable with that of direct APSD measurements. It should be remarked that the method allows determining the large particle component of the aerosol ($r \geq$ 5 µm), the part of APSD presenting some problems for direct observations. The accuracy and efficiency of the method was tested by SEAS (Shoreline Environmental Aerosol Studies) data for the lidar-deriving extinction and by direct observations over APSD [3, 4].

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14. ABSTRACT

The long-term goal is to establish reliable relationships between the environmental factors (such as wind, waves, air humidity, etc.) and the propagation of electromagnetic signals in the lower part of the marine atmospheric boundary layer (LP MABL).

15. SUBJECT TERMS

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WORK COMPLETED

The investigations were conducted along the following lines:
1.   The test of the method of mean ordinates by the experimental SEAS data;
2.   The use of direct observations over APSD for inverting lidar data;
3.   The derivation of horizontal profiles of aerosol microphysical characteristics in LP MABL from SEAS lidar measurements.

1. The previous-year tests, which gave encouraging results, had been performed with preliminary experimental data. The SEAS data used this year were final in that they were completely corrected and brought to mutual consistency [3, 4]. The tests were performed for two initial sets of aerosol models. The first set was based on aerosol information available in literature [5, 6]. For the second set, we used SEAS experimental data on APSD with the addition of the fourth, large-sized component [6]. The inversion results for both initial parameter sets are presented on Fig. 1.
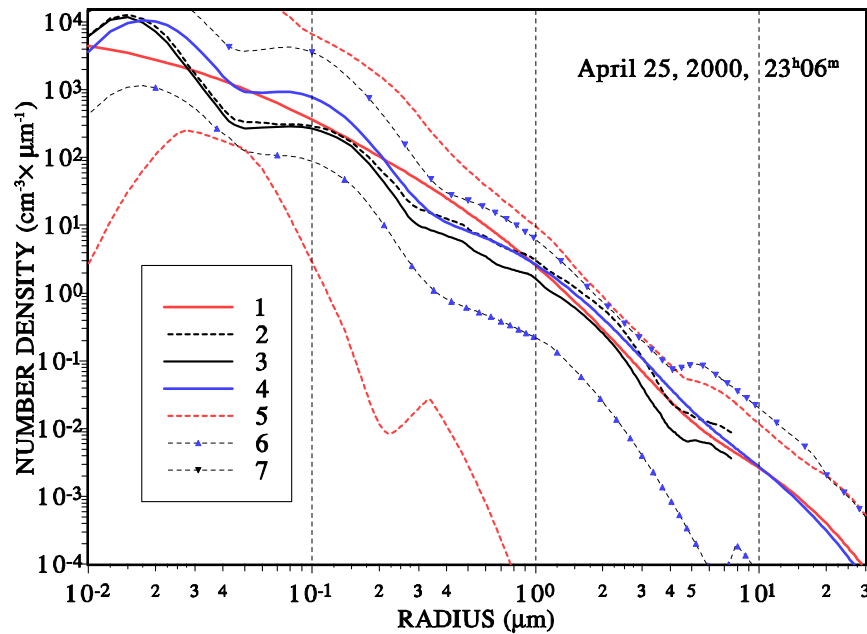
Fig.1. Inversion results by the method of mean ordinates for 23h 06m, April 25, 2000.
1, inversion with the use of the first set of initial parameters; 2, measured APSD at the 5 m level; 3, measured APSD at the 15 m level; 4, inversion with the use of the second set of initial parameters; 5, curves of lower and upper envelopes of the ensemble of acceptable solutions for the first set of initial parameters; 6,7 curves of lower and upper envelopes of the ensemble of acceptable solutions for the second set of initial parameters.
[The curve by inversion is confined between the experimental APSDs on the optically active particle size interval (0.5-5 μm), which proves the efficiency of the method]

It is seen that the main difference between the APSD by inversion for the first set and the experimental APSDs at 5 and 15 m above the ground is that the curve by inversion is smoother that the other two. In the experimental curves, the modes of the small- and medium-sized particle components are clearly defined, whereas in the curve by inversion, they are imperceptible. The small-particle mode of the curve by inversion interpolates the first two modes of the experimental curve. This is no surprise, since

the APSD by inversion was obtained with a priori notion of the marine aerosol and by using a single value of the aerosol extinction. The inversion results for the second parameter set show a noticeable improvement as to the first set. It is seen that the calculated APSD is as elaborated as the experimental ones. The third component is close to the experimental third component in terms of mode position, width, and height. The positions of the first and second modes are reproduced quite satisfactorily, although the heights of distributions differ, sometimes significantly so. The latter fact is of little importance, because the contribution of the first two components into the total aerosol extinction is practically of the same order as its error.

Unfortunately, SEAS did not include observations over aerosol particles larger than 7.5 μm. This component is generated by surf and lives a very short time [6]. Nevertheless, its optical effect can have an impact on the propagation of a lidar beam near the sea surface. From our inversion results, the mode of this component falls on a size interval of 5.4-8.6 μm. Its particle concentration varies from moment to moment between 0.02 and 0.06 cm^{-3},

As it is clear from Fig. 1, the area of acceptable solutions for the second set of initial parameters is noticeably narrower than for the first set. We mean the area between the lower and upper curve 5 for the first set, and between curves 6 and 7 for the second set. The reason for this is that real experimental data were used in the second case.

2. Extensive numerical experiments proved the efficiency of a constraint imposed on the inverse problem both for smooth and non-smooth APSD. We made an effort to use the directly measured APSD as such a constraint. The results are shown on Fig. 2.
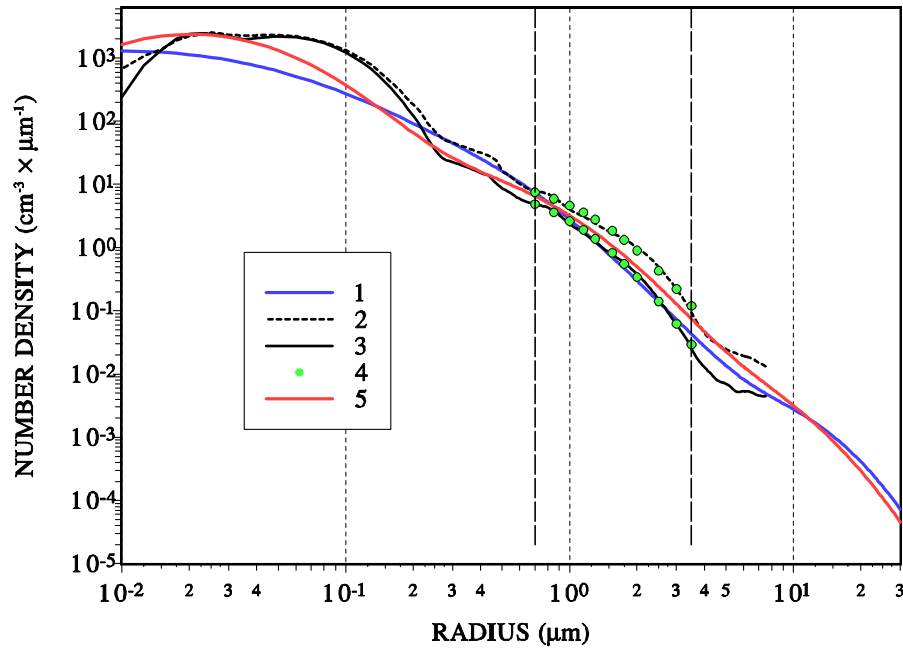
***Fig. 2. Inversion results with a constraint on the 0.7-3.5 μm interval for 0h 09min, April 29.
1, inversion without a constraint; 2, APSD data for the 5m height; 3, APSD data for the 15m height;
4, constraints; 5, inversion with a constraint.
[Inversion with constraint reveals the mode with a maximum at 1μm and the inflection at the
transition to smaller particles]***

Fig. 2 basically confirms the theoretical conclusions about the efficiency of the APSD constraint.
However, the SEAS experimental data for APSD were obtained at two levels, 5 and 15 m. The limits
of the constraint were necessarily dictated by the difference between ASPD at the two levels, which
was about 80%. As a result, the constraint was not strict enough to improve the inversion remarkably.
Nevertheless a certain improvement is evident. In particular, the APSD by inversion with constraint is
now confined between the two experimental ones on a wider size interval of 0.2-7.5 μm. The main
change to the better is that in the curve by inversion, the mode with a maximum at 1 μm is now visible
quite clearly, as also is the inflection at the transition to smaller particles. The use of constraint on a
narrower size interval of 0.7-2-0 μm yields similar results. Judging from the numerical experiments,
the acceptable limits of the APSD constraint should be of an order of 30% or better in order to improve
the inversion more significantly.

3. Using SEAS data at 0.532 μm (the only data that could be considered reliable at that time), we
determined the total aerosol particle concentration n_{ef}, effective mean particle radius r_{ef}, and effective
mean variance σ^2_{ef} as functions of the aerosol extinction σ, and constructed profiles of the above
quantities from 300 m to 1 km offshore. Figs. 3 shows the σ-dependence of the particle concentration.
The behavior of the other two quantities is similar to that on Fig. 3.
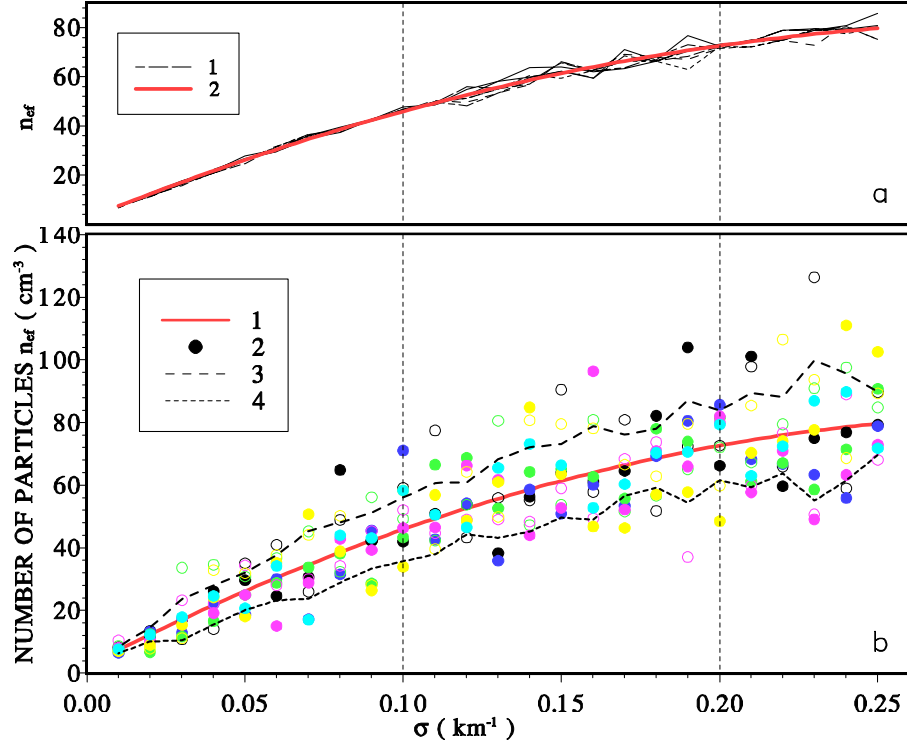
Fig. 3. n_{ef} as a function of σ.
a)1, n_{ef} for eight most probable solutions; 2) parabolic approximation;
b) 1, parabolic approximation; 2, n_{ef} as the mean over eight APSD for
different samples; 3.4, standard deviations from the approximation.
[n_{ef} grows parabolically with σ]

Obviously they grow with σ. It follows, in particular, that in sprays, not only the particle concentration increases, but the particles themselves grow, and the effective distribution width becomes wider than it is outside the sprays. It should be noted that the particle concentration grows with σ somewhat slower than a linear proportion.

Using σ-dependencies of the aerosol particle concentration, effective radius, and effective mean variance, we retrieved their profiles along the lidar beam path. Examples of such profiles are shown on Fig. 4.

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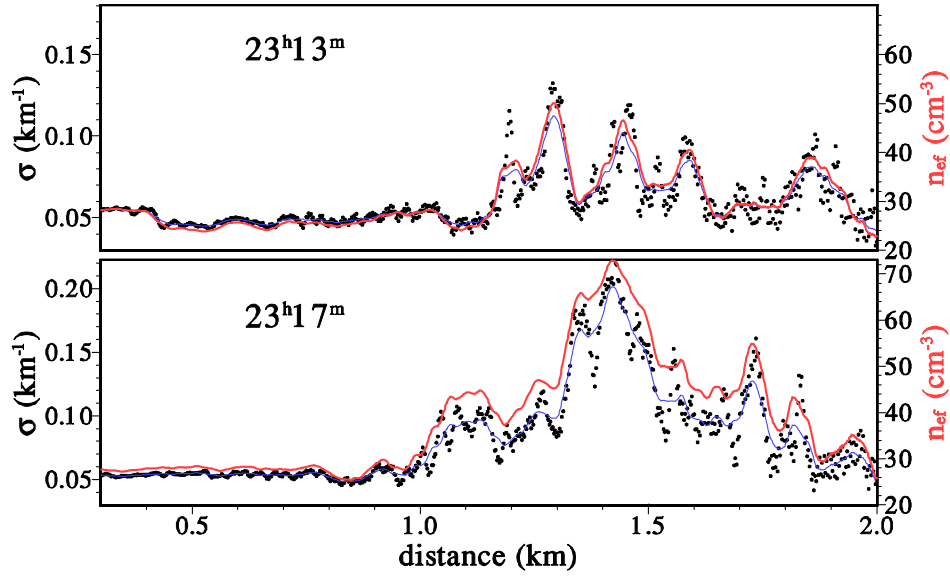
Fig.4. Behavior of n_{ef} along horizontal lidar trajectories.
Black circles, values of measured σ. Blue curves, σ smoothed over intervals of 25 m. Red curves, n_{ef}
obtained with the function on Fig.3a.

RESULTS

•   The use of a constraint in a form of APSD data even on a limited size interval improves the inversion of lidar data into APSD on the entire aerosol particle radius interval.

•   It is of primary importance that the APSD constraint is applied to an optically significant size interval. The width of the applied constraint is of lesser importance**.**

•   The test results with real experimental data confirm the theoretical conclusions about the efficiency of the method of mean ordinates for inverting lidar data into APSD. The recourse to constraint improved the inversion results somewhat further, but lacking stricter constraining conditions, it is hard to predict how far one can advance in that direction.

•   It is possible to retrieve horizontal profiles of the aerosol particle concentration, effective radius, and effective mean variance from lidar data at one wavelength.

IMPACT/APPLICATIONS

The tests with the SEAS database confirmed the efficiency of the method of mean ordinates and established the limits of its applicability, thus securing a new reliable method for inverting optical data into aerosol microphysical characteristics.

RELATED PROJECTS

Our method for retrieving APSD from optical observations is being used in our NASA-funded project "The Refinement of the Atmospheric Correction Algorithm for Determining the Marine Chlorophyll Concentration from Space".

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